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Identifying the Criteria of Cadmium Pollution in Paddy Soils Based on a Field Survey

Weichang Ji[a], Zhongqiu Chen[b], Dan Li[a], Wuzhong Ni[a]*

[a]*College of Environmental and Resource Sciences, Zhejiang University, and MOE Key Lab of Environment Remediation and Ecosystem Health, Hangzhou 310058, P. R. China*

[b]*Centor for Agricultural technique Extension of Shangyu City, Shangyu 312300, P. R. China*

Abstract

In this paper, a field survey was conducted to evaluate the criteria of cadmium pollution in paddy soil. A set of 32 samples of paired grain, straw, and topsoil (0-20) were collected, and Cd concentrations in soils and rice plants were determined by an ICP-MS. The results indicated that Cd concentrations of fifteen soil samples were excessive to the value of maximum allowable limit (MAL) for cadmium in soil (1.0 mg kg^{-1}), and Cd concentrations of five brown rice samples were excessive to maximum level for cadmium in rice (0.2 mg kg^{-1} dry matter). It was found that Cd concentrations in straw and brown rice are significantly (P<0.01) correlative to the Cd concentrations in topsoil with the correlative coefficients 0.800** and 0.907**, respectively. Using the regression equation and maximum level for cadmium in rice, the criteria of Cd pollution in paddy soil modified as 1.5 mg kg^{-1} was recommended. Cadmium concentration in straw could be used for early distinguishing the status of cadmium contamination of rice grain.

Keywords: Cadmium; criteria; paddy soil; pollution; rice

1. Introduction

Cadmium (Cd) is regarded as one of the most toxic trace elements in the environment with no function in any biological organism. The increased emissions resulting from its production, use, and disposal, combined with its persistence in the environment, and its relatively rapid absorption and accumulation by food crops contribute to its potential environmental hazards. Cadmium in soils is readily taken up by

* Corresponding author. Tel.: +086-0571-88982055.
E-mail address: wzni@zju.edu.cn.

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plants and is not phytotoxic at concentration in crops that can significantly increase human exposure [1, 2]. Excessive exposure to Cd has been associated with various illnesses in humans, including gastroenteritis, renal tubular dysfunction, hypertension, cardiovascular disease, pulmonary emphysema, cancer, and osteoporosis [3, 4]. For example, elevated levels of Cd in the diet and drinking water were concluded to be causative factors in the 1964 occurrence of Itai Itai disease (severe osteoporosis/osteomalacia and renal tubular dysfunction) in the Toyoma Prefecture in Japan [5]. Natural as well as anthropogenic sources of cadmium, including industrial emissions and the application of fertilizer and sewage sludge to farm land, may lead to contamination of soils, and to increased cadmium uptake by crops and vegetables, grown for human consumption [3, 6]. Cadmium pollution in arable soil is worldly concerned, and has been issued in soil environmental quality in many countries. But the values of maximum allowable limits (MAL) for Cd in soil used are extremely different [7]. As rice plants are generally tolerance to Cd stress, the evaluation of the criteria of cadmium contamination in soil is significant.

The objective of the reported work was to study the relationships between cadmium concentration in paddy soil and in rice plant with a practical field survey. Than, the criteria of Cd pollution in paddy soil based on the hygienic limit of Cd in rice was evaluated.

2. Materials and methods

For evaluating the criteria of cadmium pollution in paddy soil, a practical survey was conducted in the site formerly receiving zinc/lead mine discharge, had being partially cleaned and re-ploughed in Shangyu City, Zhejiang Province, China (latitudes 30˚01'N and longitudes 120˚52'E). A set of 32 samples of each paired grain, straw, and topsoil (0-20) were collected at rice harvest stage, with one sample set per field sampled. The soil samples were air-dried, dissagregated and passed though a 0.25mm nylon screen, and than homogenized. Rice grain samples were firstly air-dried, and than separated into brown rice and husk. Rice straw, brown rice and husk were oven-dried at 60°C to constant weight and ground in a stainless steel mill. Both of soil and plant samples homogenized were stored in polyethylene containers until the analysis was carried out [8].

For the determination of cadmium concentration in the paddy soil, the homogenized sample (0.5 g) was digested with aqua regia and diluted to 100 mL with 2% HNO_3. For the determination of cadmium concentration in plant tissues, dry plant material (1.0 g) was placed in porcelain crucibles and mineralized by the oven-drying digestion methods. Digested plant samples were dissolved, filtered and brought to 25-mL with 0.5ml L^{-1} HNO_3. Cadmium concentrations in digested solutions of soil or plant samples were analyzed using an ICP-MS (Inductively Coupled Plasma Mass Spectrometer, Agilent 7500a) [8].

Maximum allowable limit (MAL) for cadmium in soil used in this work is 1.0 mg kg^{-1} soil [9] and maximum level for cadmium in rice is 0.2 mg kg^{-1} (dry matter) [10].

3. Results and discussion

3.1. Cadmium concentration in soils

The total cadmium concentrations in paddy soil collected from the field survey conducted in Shangyu City, Zhejiang Province, China were presented in Table 1. The analytic results indicated that the total Cd concentrations in paddy topsoil (0-20 cm) range from 0.56 to 8.77 mg kg^{-1}, with an average as 1.34±1.45 mg kg^{-1}. With the comparison to the value of maximum allowable limit (MAL) for cadmium in soil (1.0 mg kg^{-1}) [9], cadmium concentrations of fifteen samples were excessive, contributing to 46.9% of the total 32 soil samples analyzed, and implying that the field land represented by these samples were contaminated with cadmium.

Table 1. Cadmium concentrations in soils and rice plants

Sample number	Cadmium concentration (mg kg^{-1})			
	Soil	Straw	Brown rice	Husk
1	3.37	0.61	0.51	0.19
2	8.77	1.39	0.96	0.36
3	1.44	0.17	0.06	0.12
4	2.21	0.78	0.18	0.18
5	1.51	0.29	0.07	0.13
6	1.28	0.21	0.06	0.14
7	0.93	0.67	0.14	0.24
8	1.13	0.40	0.09	0.26
9	1.15	0.26	0.08	0.16
10	1.43	0.16	0.06	0.14
11	0.84	0.10	0.06	0.12
12	0.91	0.11	0.03	0.08
13	0.79	0.10	0.04	0.11
14	1.25	0.39	0.11	0.16
15	1.04	0.16	0.05	0.09
16	1.01	0.24	0.10	0.13
17	1.04	0.22	0.07	0.09
18	0.97	0.27	0.09	0.08
19	0.94	0.15	0.16	0.07
20	0.85	0.40	0.20	0.10
21	0.91	0.40	0.21	0.15
22	0.56	0.41	0.15	0.10
23	1.20	0.24	0.12	0.09
24	0.94	0.21	0.10	0.07
25	1.01	0.17	0.09	0.06
26	0.80	0.42	0.23	0.14
27	0.82	0.50	0.06	0.11
28	0.85	0.24	0.11	0.07
29	0.84	0.38	0.18	0.11
30	0.71	0.45	0.19	0.12
31	0.63	0.23	0.10	0.07
32	0.67	0.27	0.15	0.09

3.2. Cadmium concentration in rice plants

The cadmium concentrations in rice straw, brown rice and husk collected from the field survey were also presented in Table 1. The results indicated that Cd concentrations in brown rice range from 0.03 to

0,96 mg kg^{-1}, with an average as 0.15±0.17 mg kg^{-1}. According to maximum level for cadmium in rice [10], cadmium concentrations of five brown rice samples were excessive, contributing to 15.6% of the total 32 samples analyzed, and implying that the harvested grain represented by these samples were contaminated with cadmium. From Table 1, it was also found that Cd concentrations in rice straw range from 0.10 to 1.39 mg kg^{-1}, with an average as 0.34±0.25 mg kg^{-1}, and Cd concentrations in rice husk range from 0.06 to 0,36 mg kg^{-1}, with an average as 0.13±0.06 mg kg^{-1}. In general, Cd concentration in rice straw was obviously higher than that in brown rice or husk.

3.3. Evaluation of criteria of cadmium pollution in paddy soil

In Table 1, it could be observed that cadmium concentration in straw or brown rice increased with the increasing of cadmium concentration in soil. The results of correlative analysis are shown in Table 2. Cadmium concentrations in straw and brown rice are significantly (P<0.01) correlative to the Cd concentrations in topsoil with the correlative coefficients 0.800** and 0.907**, respectively. Cadmium concentration in brown rice is significantly (P<0.01) correlative to Cd concentration in straw with the correlative coefficient 0.852**, as well. In many cases, a linear relationship between Cd in plant material versus Cd in growth medium was reported (Filip et al., 1998; Ni et al., 2002; Ni et al., 2004). As the regression coefficient was significant at the level of 1% (P<0.01), the regression equation of Cd concentration in brown rice versus Cd concentration in soil could be used to estimate the threshold of cadmium concentration in soil based on maximum level for cadmium in rice (0.2 mg kg^{-1} dry matter, GB 2762-2005 in China). The regression equation of Cd concentration in brown rice versus Cd concentration in soil obtained was as follows:

$$Crice = 0.1080Csoil + 0.0034 \quad (1)$$

Where Crice is Cd concentration in brown rice and Csoil is Cd concentration in topsoil of paddy.

Table 2. Correlative coefficients of Cd concentration in straw or brown rice versus Cd concentration in soil

	Csoil	Cstraw	Crice
Csoil	1		
Cstraw	0.800**	1	
Crice	0.907**	0.852**	1

"**" means that the coefficients are significant at 1% level (P<0.01).

According to the regression equation, the threshold of cadmium concentration in soil calculated is 1.82 mg kg^{-1}, which is higher than the value of maximum allowable limit (MAL) for cadmium in soil used in China [9], and much lower that used in some developed countries (Table 3) [7]. Therefore, the criteria cadmium concentration in paddy soil could be recommended as 1.5 mg kg^{-1} soil.

The regression equation of Cd concentration in brown rice versus Cd concentration in straw was also obtained, and was as follows:

$$Crice = 0.5838Cstraw - 0.0515 \quad (2)$$

Where Crice is Cd concentration in brown rice and Cstraw is Cd concentration in rice straw.

As the regression coefficient was significant at the level of 1% (P<0.01), the slope of the regression equation could be used as a parameter factor for estimating Cd concentration in rice from Cd concentration in straw. For more safety, the coefficient parameter can be modified from 0.5838 to 0.6, making the assessment of the status of Cd pollution in rice grain simplified.

Table 3. Values of Maximum Allowable Limits (MAL) for heavy metals in soil used in different countries

Heavy metal	Maximum Allowable Limits ($mg\ kg^{-1}$)					
	Austria	Canada	Poland	Japan	Great Britain	Germany
Cd	5	8	3	-	3	2
Ni	100	100	100	100	50	100
Pb	100	200	100	400	100	500

4. Conclusions

With the field investigation, the status of Cd pollution in soils and grown rice in the site sampled, and the correlative relationships between Cd concentrations in soils and rice plants were identified. Based on the regression equation and maximum level for cadmium in rice, the criteria of Cd pollution in paddy soil was estimated as 1.5 mg kg^{-1}. It is suggested that Cd concentration in straw can be used to assess Cd contamination in grains before rice harvest.

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